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26 May 1993 2/15/92 to 2/14/93 Annual

Reference Frames in Vision

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Prof. Mary M. Hayhoe

Center For Visual Science
College of Arts And Science
University of Rochester, NY 14627

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AFOSR/NL
110 Duncan Avenue, Suite B115
Bolling AFB DC 20332-0001
Lt Col Collins

Summary of an Annual Progress Report

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This research examines the consequences of observer motion for visual functioning. Two major visual issues are addressed. The first issue is how a grossly time-varying retinal input (due to eye, head, and body motion) results in the perception of a continuous and directionally stable world. The second issue concerns the relatedness of the visual information that is retained from previous viewing. An examination of'deictic primitives' (e.g., fixation points) and their importance for accurate internal representations is being investigated by covarying the temporal access to the sensory input during the problem solving process.

Preliminary observations reveal some notable features of theeye and head coordination: 1) Head movement fequently leads the gaze change and 2) The fraction of gaze shift due to head movement varied from 20% for short, vertical movements, tonearly 100% for large horizontal movements. It was in general dependent on the sub-task, and was larger for horizontal than vertical gaze changes. In addition, it was shown that the gaze moved first to the model area, then is refined down to the workspace, while the head simply moves to the model area.

deictic primitives, robotic models, observer motion, retinal input, orientation, saccade-contingent display update 4

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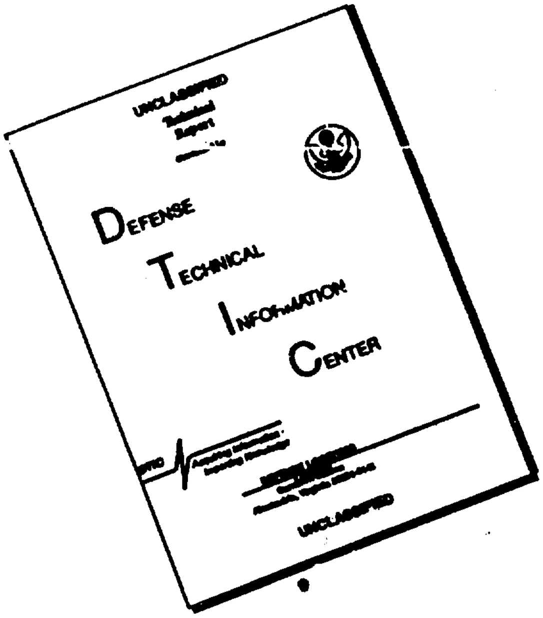

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COLLEGE OF ARTS AND SCIENCE
CENTER FOR VISUAL SCIENCE

May 26, 1993

Lt. Col. Daniel Collins
AFOSR/NL
Bolling Air Force Base
Washington, DC 20332-6448

Dear Lt. Col. Collins:

Annual Technical Report: AFOSR No 91-0332. Reference Frames in Vision
Period 2/15/92-2/14/93

The goal of this project is to examine the consequences of observer motion for visual function. The research has focused on two issues: One issue is how a grossly time-varying retinal input (because of eye, head, and body motion) results in the perception of a continuous and directionally stable visual world. A second issue concerns how the information in successive views is related, and the nature of the visual information retained from previous views. Understanding these processes is important for a wide variety of visuo-motor tasks.

Three graduate students, two undergraduate lab assistants, and a post doctoral fellow have participated in the project. The students are Jeff Pelz, Keith Karn, and Joel Lachter. The post doc is Steve Whitehead. Whitehead moved to another position at GTE labs in August, but has continued to collaborate on the project. Lachter is currently writing up his thesis and should graduate shortly. They are supported by a combination of funds from this grant, an NIH training grant, and University funds.

My primary effort has been on two projects with Dana Ballard, Jeff Pelz and Steve Whitehead, on performance of complex tasks involving hand-eye coordination. In the earliest version of the task we presented stimuli on a Mac screen and monitored eye and cursor position. In the recently developed version of the task we use real blocks and monitor eye, head, and hand position.

Copying Task Using Macintosh Display.

In the task we have chosen, subjects copy a pattern of colored blocks on a computer screen using the mouse to move blocks around the display. Recent successful robotic models of complex tasks avoid computationally expensive internal representations by allowing frequent access to the sensory input during the problem solving process. These models use so called 'deictic primitives' in which aspects of a scene can be referred to by denoting that part of the scene with a special marker, such as the fixation point. We have little knowledge of how humans actually perform in comparable sensori-motor tasks. We have shown so far that human performance is also characterized by deictic strategies and limited memory representations. This suggests that current approaches in robotics are also useful for understanding human brain mechanisms. It also suggests a computational rationale for the limitations on human working memory. The limited nature of human working has been taken as a kind of explanatory primitive in understanding cognitive processes. However, there has been surprisingly little effort directed at understanding *why* it is limited, and how these limitations

274 Meliora Hall
University of Rochester
Rochester, New York 14627

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play themselves out in normal behavior. The 'active vision' approach in robotics forces a new consideration of the computational role of short term memory. It seems likely at this point that there is a real advantage to be gained by such a system in terms of simplifying the underlying cortical decision making processes and minimizing the need for a central executor. A better understanding of how the system works as a whole should provide better guidance in how to approach the underlying neural organization. We have prepared a manuscript on this work which will shortly be submitted to Nature. The work was presented at the Spring meeting of ARVO, and at the European Conference on Visual Perception.

Analysis of task sub-structure. As well as examining performance at the overall level of strategies used, we have also analyzed performance at the level of the individual actions. Analysis of the fixation patterns, for example, has suggested that fixation has a bookkeeping role, keeping track of where the subject is in performing the task. We are continuing this kind of analysis. Many aspects of the data remain to be analyzed, concerning the programming of the eye and hand movements, and the timing of the cognitive operations involved in task performance. We will use this data to elaborate our current computational model of the task.

Experiments involving Saccade-Contingent Display Updating. One important general class of experiments involves changes in the visual display during a saccade. In the current grant period we have written programs to do this in the experimental set up where the head is fixed and the eye monitored by the DPI eyetracker and block movements are made using the mouse. Using these newly developed programs, there are three major classes of questions we will investigate: 1. What is the nature of the visual information retained from previous views? 2. What are the reference frames for programming the various movements in the task? 3. What is the nature of the sub-components of the task.

Copying Task in a Natural Environment

In addition, we have begun investigation of performance using real blocks and hand movements, with the subjects' head free to move, using an ASL head-free eye and head tracker, and a magnetic hand coil. (This equipment was bought on an NIH Resource Development Grant. Development of the laboratory was undertaken by Pelz and an undergraduate lab assistant supported by the grant. A new Mac to run this system will also be purchased using AFOSR funds, in order to improve the temporal sampling rate.) This has provided important validation of our task in more natural conditions in addition to revealing a number of new findings. Subjects in the natural task perform in the same stereotypical way as in the Mac task, characterized by frequent eye movements to the model pattern. Thus the use of short term memory is extremely limited, even to the extent that properties of a single block are acquired separately. Even when the cost of references to the environment was increased by moving the model and workspace 70 deg apart (requiring large head movements), the subject still made frequent reference to the model. Conversely, other experiments revealed that performance declined precipitously when frequent access to the model during task performance was prohibited.

Subjects differ in the frequency with which they make return saccades to the model but are remarkably similar in other aspects of performance, such as fixation duration, time for pick up and for put down. In addition, the time spent in the model area does not change significantly in the course of the trial, indicating that very little learning of the model takes place.

Preliminary observations reveal some notable features of the eye and head coordination: 1) Head movement frequently leads the gaze change and 2) The fraction of gaze shift due to head movement varied from 20% for short, vertical movements, to nearly 100% for large horizontal movements. It was in general dependent on the sub-task, and was larger for horizontal than vertical gaze changes. 3) Head and gaze paths are commonly observed to diverge. While the head performs a single movement from the resource area to the workspace

after picking up a block, the gaze moves first to the model area, then down to the workspace. This suggests that the eye and head are not driven by a single, central motor command.

Other Studies.

Keith Karn has begun an investigation comparing the effect of external reference frames on perception and reaching. Perception and action have often been thought to involve different neural channels. Karn is examining the hypothesis that the differences are more simply accounted for in terms of the reference frame used for the task in question. These experiments will for the basis for his dissertation, which he plans to complete by the end of the year.

Jeff Pelz and I have also continued work on our investigation of the role of the visual scene in visual stability and direction constancy, using an afterimage technique (see previous reports). We have made some further observations on the nature of the eye movements which can suppressed when a normal scene is present, and have prepared a manuscript which will be submitted to Vision Research very soon

Joel Lachter has continued experiments on how much visual information gets processed outside the focus of attention. He is using a novel technique introduced by Rock to look at this question. Data collection is now complete and he is writing his thesis. His experiments suggest that visual processing outside the focus of attention is minimal Lachter and I have also worked on a manuscript on the role of attention in integrating information across saccades. We plan to finish this in a month or two.

RELEVANT PUBLICATIONS

Hayhoe, M.M., Lachter, J. & Moeller, P. (1992) Spatial memory and integration across saccadic eye movements. In K. Rayner (Ed.), *Eye Movements & Visual Cognition*. Springer-Verlag. pp. 130-145.

Karn, K., Moeller, P., and Hayhoe, M. Precision of the eye position signal. (1992) in Van Rensbergen, J. & d'Ydewalle, G. (Eds.), *Studies in Visual Attention*. North Holland. pp. 71-82.

Ballard, D., Hayhoe, M., & Whitehead, S. (1992) Hand-Eye coordination during sequential tasks. *Phil Trans Roy Soc Lond B.*, 331-339.

Hayhoe Ballard Whitehead 1993 Memory Use During Hand-Eye Coordination. *Proceedings of the Cognitive Science Society.*

MANUSCRIPTS IN PREPARATION

Ballard Hayhoe Whitehead Memory Use During Hand-Eye Coordination (in preparation).

Moeller, P., Hayhoe, M., Ballard, D., Albano, J. Saccades to remembered visual targets and the perception of spatial position. (in preparation).

Lachter, J., Hayhoe, M. & Feldman, J. Capacity limits in the integration of information across saccades. (in preparation).

Pelz, J. & Hayhoe, M. Influence of the visual scene in space constancy. (in preparation)

Karn, Hayhoe & Moeller Effect of Intervening eye movements on saccades to remembered visual targets. (in preparation).

PRESENTATIONS AT SCIENTIFIC MEETINGS

Ballard, D., Hayhoe, M., Li, F., and Whitehead, S. (1992) Hand-eye coordination during complex tasks. Presented at the annual meeting of the Association for Research in Vision and Ophthalmology, Sarasota, Florida.

Hayhoe, M., Ballard, D., Li, F., and Whitehead, S. (1992) Hand-eye coordination during complex tasks. Presented at the European Conference on Visual Perception.

Sincerely yours,

Mary Hayhoe

Mary M. Hayhoe

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